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ANALYSIS OF REQUIREMENTS FOR COMPUTER CONTROL AND DATA PROCESSING EXPERIMENT SUBSYSTEMS

S-056 EXPERIMENT
IMAGE DATA PROCESSING SYSTEM
SOFTWARE CALIBRATION AND APPLICATION
SEQUENCE STUDY
FINAL REPORT

20 FEBRUARY 1974

SYSTEM DEVELOPMENT CORPORATION

TECHNICAL MEMORANDUM

(TM Series)

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FOREWORD

This document was produced under NASA contract number NAS8-25471 "Analyses of Requirements for Computer Control and Data Processing Experiment Subsystems". It was prepared by the Huntsville Space Projects staff of System Development Corporation for the Computer Systems Division of the George C. Marshall Space Flight Center's Computation Laboratory. The work which formed the basis for this report was performed during the period from September 15, 1973 to January 15, 1974 and was performed under the technical direction of Mr. Doug Thomas, Contracting Officer's Representative for the project. Appreciation is expressed to Mr. Thomas, to Mr. Bobby Hodges of the MSFC Computation Laboratory and to Mr. James Milligan, Principal Investigator of the S-056 experiment, for their support and valuable assistance during the course of the project.

The following report documents the results of efforts by the System Development Corporation project team to develop software calibration data and to establish an optimum sequence of image processing technique application for use in future processing of S-056 images.

SECTION 1. INTRODUCTION

Space experimentation in the Skylab program is now complete. The film has been removed from the ATM telescopes and returned to earth for examination. Throughout the three manned missions of the Skylab program and for several years prior to the flights, System Development Corporation (SDC) has been studying the requirements for handling data from ATM experiment S-056. These efforts have centered on the problem of processing photographic images produced by S-056 and on the study of hardware/software tools needed to do that processing. SDC has cataloged image processing techniques needed by the experiment and has built a prototype Image DAta Processing System (IDAPS) to illustrate the usefullness of the techniques in restoring, enhancing, and analyzing S-056 films. A design was developed for a complete hardware/software system to support the image data processing requirements of S-056 on an operational basis and the design was tested through further refinement of the prototype IDAPS system. This report documents the final phase of the aforementioned effort, draws conclusions from the results of the last part of the effort, and sets forth a number of recommendations for those who will be responsible for the processing of the 35,000 frames of image data that have been produced by the experiment. Three specific topics are addressed in this report:

- Software Calibration
- Application Sequence Study
- Summary Conclusions

SECTION 2.   SOFTWARE CALIBRATION STUDY

The techniques used for processing S-056 films may be categorized in three groups -

- **Restoration** techniques seek to reverse or at least reduce the distortions which are brought on by a non-linear response of various parts of the imaging system.

- **Enhancement** techniques are applied to emphasize or modify specific characteristics of the image data so that it may be more easily analyzed by the human eye.

- **Analyses** techniques bring to bear a number of numerical and statistical tools for making measurements of the picture data.

The efforts of the past four months have largely been directed at the study of restoration techniques. It was assumed that restoration techniques will normally be applied to the S-056 image data before techniques of enhancement or analysis are used, and that if distortions do exist in the data, they must be removed before meaningful results can be obtained by enhancement or analysis. This means that accurate data must be available to describe the nature and degree of distortion in the image data if restoration processing is to be used effectively.

The success of the image restoration task will be determined by the quality of the data that can be obtained to describe these degradations. Specifically, calibration data must be derived for the S-056 image restoration software for the following image degradations:

- Telescope Optical Distortions
- Spectral Response Non Linearities
- Field Efficiency Variations
- Non Linear Film Response
- Non Linear Scanner Response

Each of these sources of degradation have been investigated to develop adequate calibration curves and to project requirements for future study. The discussions which follow are based largely on pre-flight data and published reports and on several second generation copies of real data frames from the first Skylab flight.

Much additional work needs to be done involving first generation films, additional second generation copies, Skylab telemetry data, and more refined information about S-056 film, filters, and optics as soon as such data can be made available.

2.1 TELESCOPE OPTICAL DISTORTION

An earlier report dated March 15, 1972 (TM-(L)-HU-033/005/00) discussed the possibility of correcting for optical distortions through the technique of deconvolution. It was stated that deconvolution was only valid if the optical system is shift-invarient over the field of view. In other words, deconvolution is useful for removing optical distortions where the point spread function (PSF) of the system is a two dimensional constant. This is not the case of S-056 (Ref. 1). Figure 2-1 is a photograph of a star-burst pattern of pin holes taken by the S-056 telescope in a ground test fixture. It appears from this figure that the S-056 PSF is highly position dependent. A large amount of scattering is also evident in the figure which would indicate a rather limited telescope resolution. Recent photographs from the first Skylab mission, however, contradict this since photographs of the sun contain images of extremely concentrated, very small X-radiation sources. Measurements of these radiation sources indicate that the S-056 telescope has actually achieved a spatial resolution of better than three arc-seconds. Therefore it appears that the true system PSF is different from what was predicted from pre-flight tests.

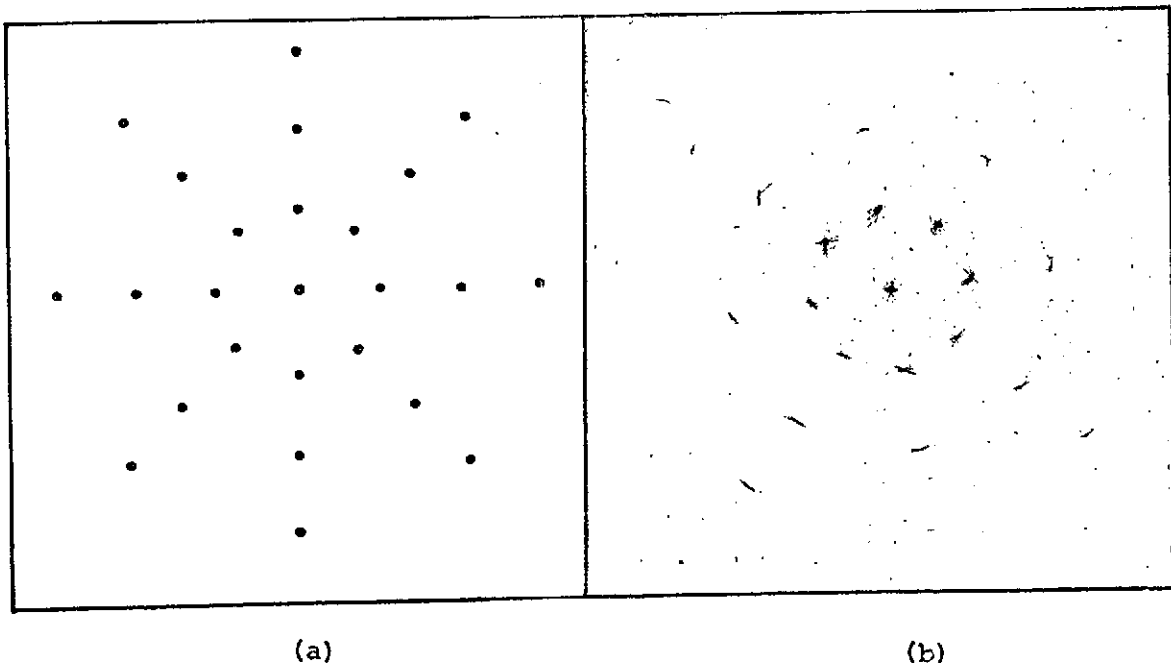(a)   (b)

Figure 2-1 S-056 telescope test using star-burst pattern of pin holes
   a) original pattern
   b) photograph of pattern taken by S-056 telescope

Numerous papers have presented methods for deriving point spread functions and optical transfer functions (OTS's) from photographic records (Ref's 2, 3, 4, & 5), but most techniques rely on the analysis of sharp edges or lines within the photographs. It is unlikely that such well defined features will be available within the S-056 data. An approach which makes an assumption of the shape and size of some small, energetic areas in the solar photographs is probably the only reasonable means for developing a system PSF. Such an approach would have to be applied in a "cut and try" fashion to arrive at a PSF which yields satisfactory deconvolution. Since deconvolution is a form of digital filtering and variations in the deconvolving PSF are analogous to varying the characteristics of the System OTF, it is recommended that subsequent efforts at S-056 image restoration be directed toward developing a good, general purpose filter based on the System OTF which can be used for making improvements over the entire field of view. By beginning with this objective, sufficient experience may be built up to allow the development of more complex filters. As an illustration of such a filter, the X-ray photograph in Figure 2-2 was digitized and the digital filter in Figure 2-3 was applied. A density slice was computer plotted along the dotted line of Figure 2-2 for both the unprocessed and filtered picture. The improvement in edge gradients can be observed by comparing Figure 2-4(a) with Figure 2-4(b). This kind of digital filtering is typical of the general purpose image processing tasks that will be of value to S-056 processing in the future.
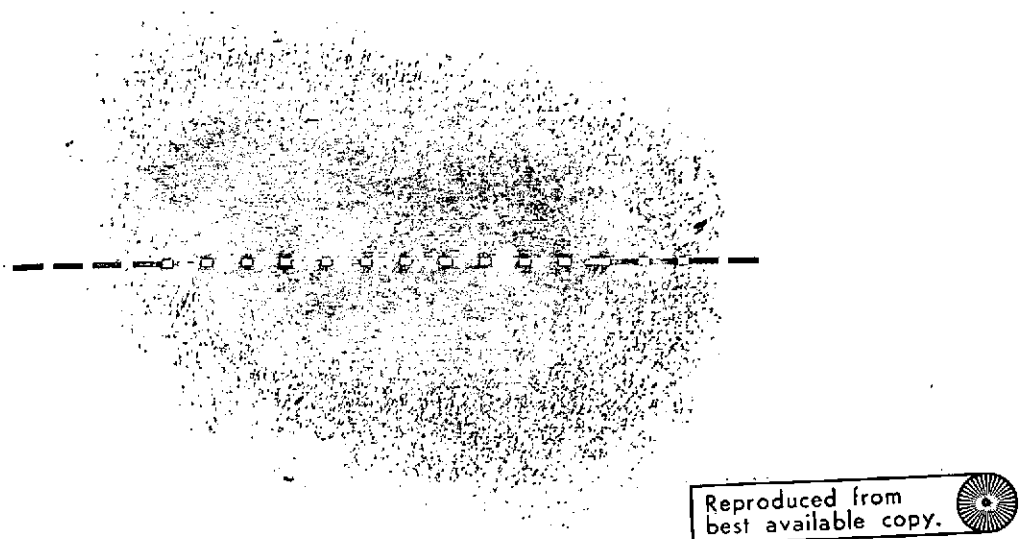
Figure 2-2   Illustrative Solar X-Ray

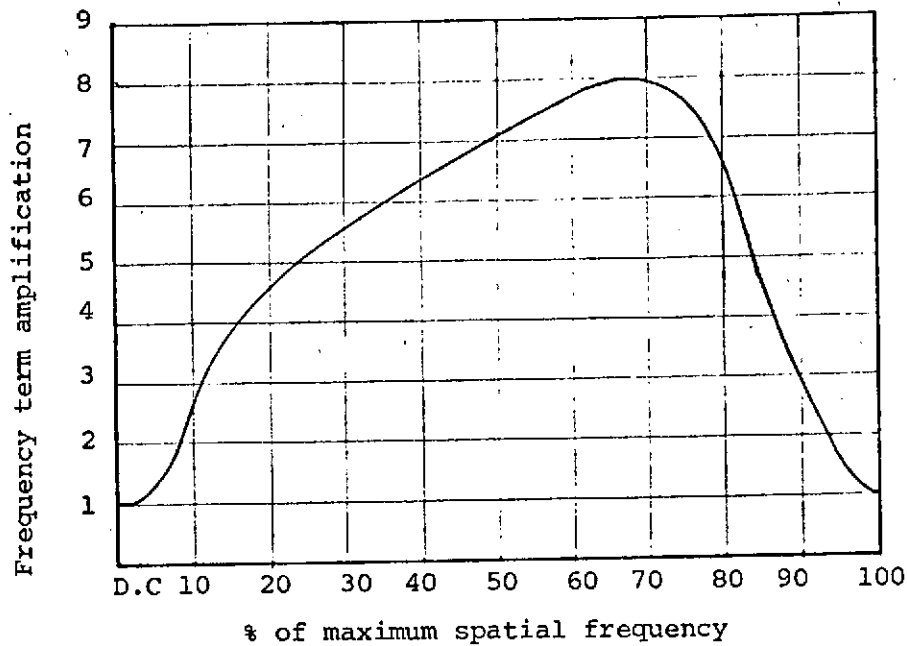Photograph Showing Path of Density Slice
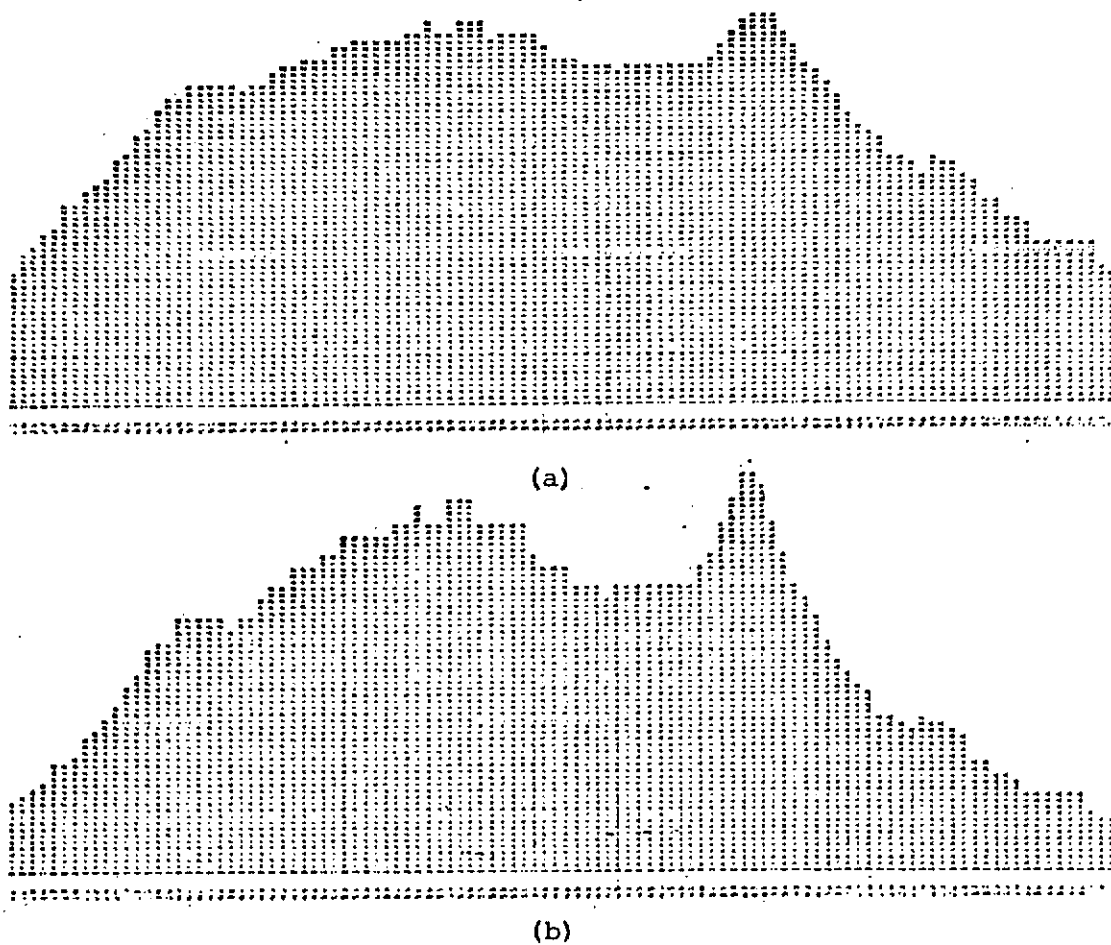
Figure 2-3   Illustrative Digital Filter

(a)

(b)

Figure 2-4   Density Slice Showing Results of High-Pass Filter of X-Ray
Photograph
(a)   unfiltered image
(b)   filtered image

2.2 SPECTRAL RESPONSE NON LINEARITIES

Normal operation of the S-056 telescope results in photographs of the sun taken
through a number of filters to provide a general spectographic capability for
the experiment. Figure 2-5(a) tabulates the pass band of these filters (Ref. 6)
and gives an indication of the spectral resolution of the instrument. Figure 2-5(b)
is a graphic representation of the same data plotted on a common base. Examination
of this plot gives an indication of how image processing might be used to separate
pass band overlap. For example, if an S-056 photograph, taken through filter #3,
shows features that do not appear in a photograph taken at about the same time
through filter #4, then the radiation must be of a 27 - 33 A radiation. Various
other such combinations will produce similar useful results. Figure 2-6 illustrates
the combination of two pictures taken through filters #2 and #3 to provide a
broadened band pass image.

Filter Number	Material/Thickness	Bandpass Range
1	BE/3 x $10^{-3"}$	5-11A
2	AL/2.5 x $10^{-4"}$	5-8, 8-20A
3	TI/8.6 x $10^{-5"}$	5-12, 27-33A
4	BE/1 x $10^{-3"}$	5-12A
5	AL/5 x $10^{-4"}$	5-8, 8-18A
6	NEUTRAL D	VIS. LIGHT

(a)
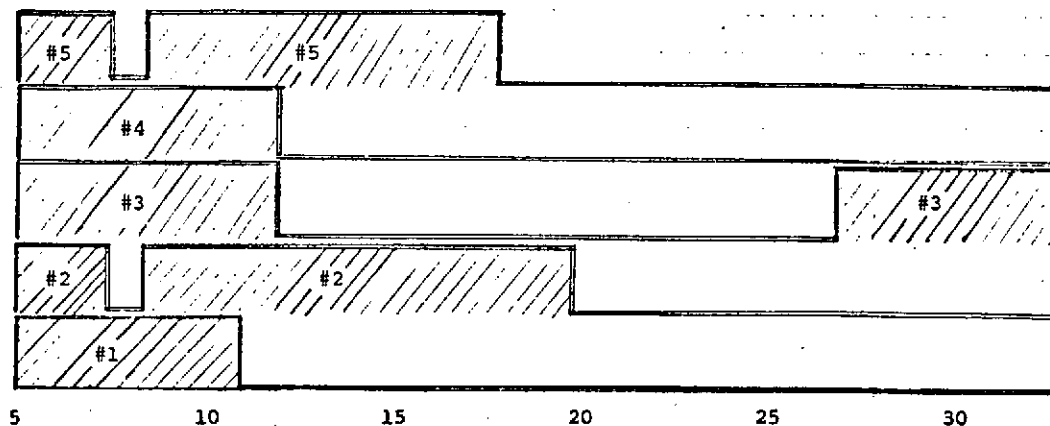
(b)

Figure 2-5 Bandpass Characteristics of S-056 Filters

(a)   (b)   (c)
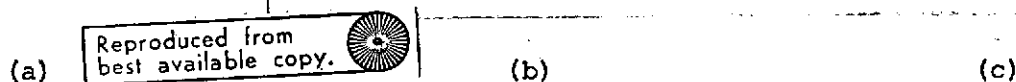
Figure 2-6   Illustrative Combination of Filtergrams

    (a)   Picture through filter #2

    (b)   Picture through filter #3

    (c)   Combination of (a) and (b)

2.3   FIELD EFFICIENCY VARIATIONS

The S-056 telescope efficiency diminishes with increasing off axis angles. Figure 2-7
presents two vignetting curves based on ray trace analysis of the telescope (Ref. 7)
and on laboratory tests of the optical system. Actual photographs from the experiment
do not appear, at least on first examination, to be as severely vignetted as
indicated by curve (b). A procedure is recommended in Section 4. of this report
for establishing the telescope vignetting characteristic from flight data which
should produce a more accurate definition of the telescope vignetting characteristic.

2.4   NON LINEAR FILM RESPONSE

The SO-212 film used in the S-056 experiment exhibits a wide dynamic range (0-4D),
a relatively low maximum gamma, and a relatively narrow mid-region linearity. The
D $\log_{10}$I characteristic for this film with 8A° sensitometry, aluminum filter, and
development in D76 at 76°F is shown in Figure 2-8. It can be seen that background
fog is about .3D and that saturation occurs at about 4D. This curve is based on the
latest available sensitometric data.

Figure 2-7   Plot of S-056 Vignetting

(a)   Ray trace prediction

(b)   Laboratory measurement
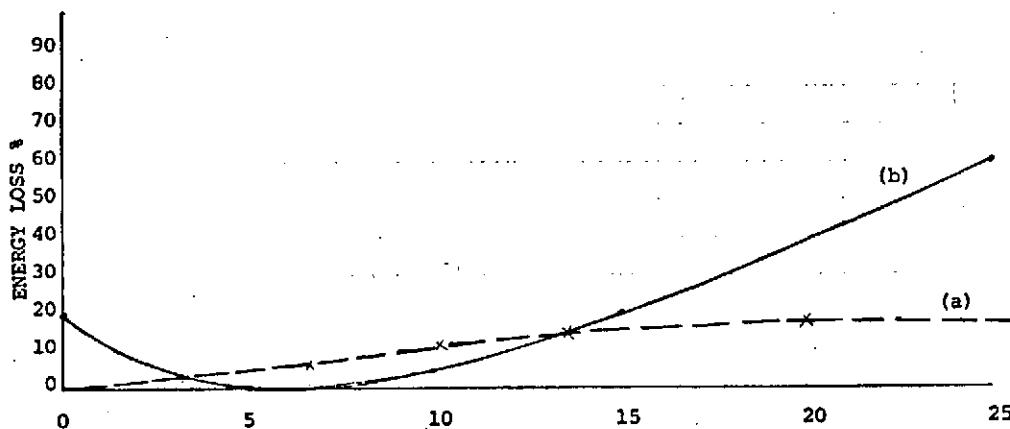
All of the real image data that has been provided from the Skylab program thus far has been in the form of second or third generation copies. The duplications were made at a high gamma so that the copy film saturated at both ends of its curve. Figure 2-9 is a histogram of the distribution of gray values from one such picture. The saturation effects result in loss of data at both ends of the gray range. Sensitometric data is not available for the present second generation copies. However, the original films are being re-copied at a lower gamma along with density calibration wedges so that in the near future, new second generation copies will be available along with the necessary calibration data so that it should be possible to fold the characteristic curve for the copy film into the characteristic of the SO-212 film and obtain an overall characteristic for the image data of the second generation copies.

2.5   NON LINEAR SCANNER RESPONSE

The last link in the S-056 image data gathering chain is the conversion of film images to digital computer readable data. This is an extremely important step because at this point a number of degradations can occur -

- Noise may be interjected in a number of forms.
- Errors might be introduced as a result of insufficient sampling frequency and quantization.
- Nonlinearities might be introduced because of non linear scanner response.

A study was conducted by personnel of Computer Sciences Corporation (CSC) of the MSFC Optronics scanning microdensitometer (Ref. 8). This study addressed each of the above three potential problem areas. Several interesting observations were made during that study and are referenced in the discussion which follows.
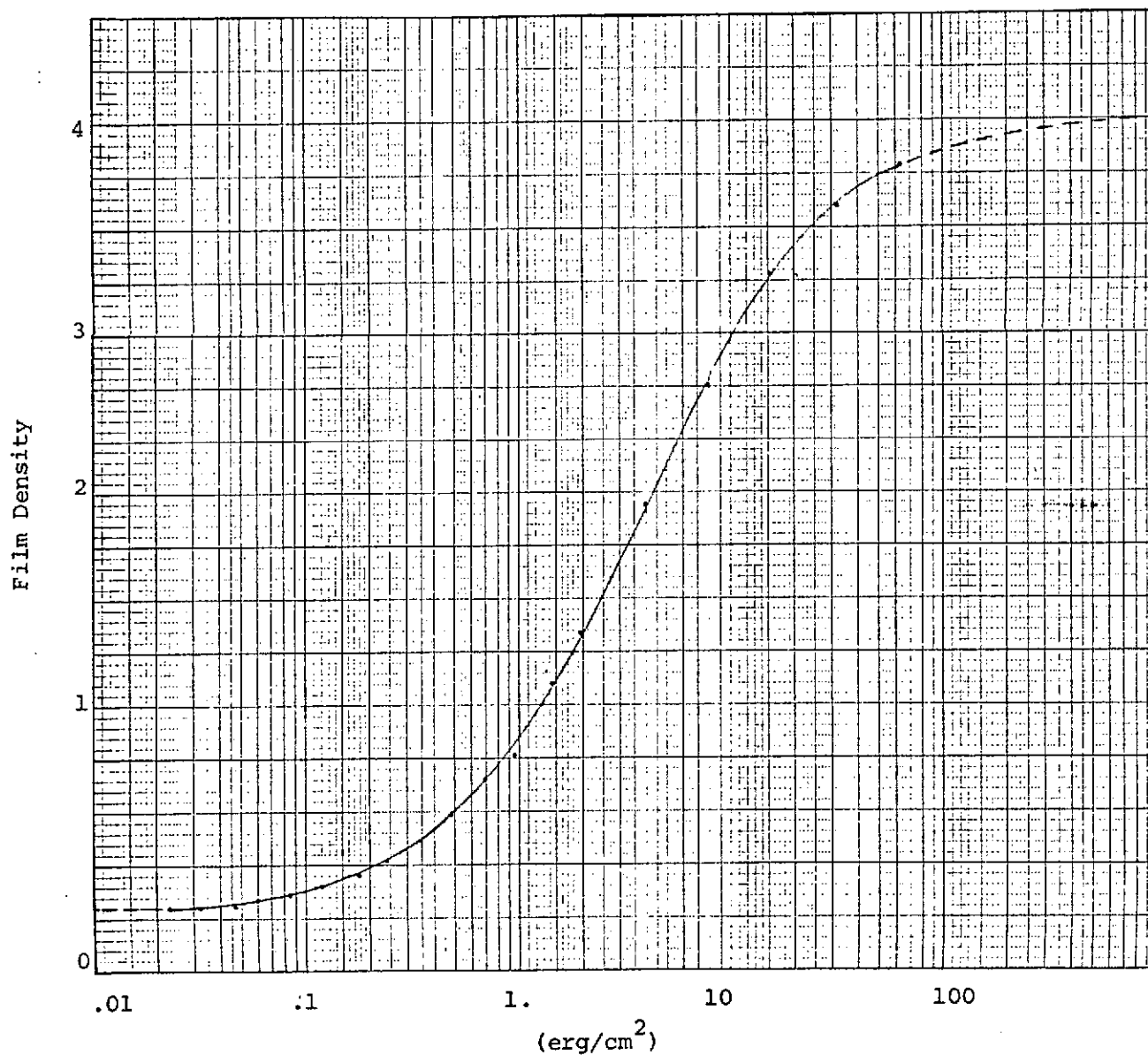

Figure 2-8 SO-212 Film $Dlog_{10}I$ Curve

DISTRIBUTION

Number of Pixels	Gray Level
0	0
0	1
0	2
1	3
1	4
51	5
57	6
49	7
61	8
60	9
67	10
74	11
75	12
79	13
67	14
78	15
81	16
80	17
78	18
96	19
90	20
106	21
114	22
138	23
146	24
157	25
257	26
330	27
365	28
374	29
430	30
482	31
490	32
593	33
716	34
782	35
759	36
902	37
963	38
1255	39
1499	40
1821	41
2076	42
2284	43
2759	44
3361	45
4077	46
5436	47
7101	48
9882	49
14540	50
28199	51
55321	52
115152	53
192225	54
213888	55
139842	56
50876	57
10043	58
863	59
0	60
0	61
0	62
0	63

Figure 2-9   Histogram of Second Generation Copy of S-056 Film

2.5.1 NOISE

Observable noise in sample test scans from the Optronics scanner is of a random nature and, as would be expected from a photomultiplier, the random noise level increases as the scanning aperture is decreased. Since there is no provision in the Optronics scanner for increasing the sample dwell time, little can be done to improve the noise figure except to maintain the scanner in as good a condition as possible.

2.5.2 CONVERSION ERROR

Sampling error is an inherent problem when converting film to digital format. The Optronics scanner samples with a 12.5, 25, 50, or 100 μm square aperture and is capable of converting analog sample values to an eight-bit byte. This should be adequate for most S-056 work considering that a 3 sec resolution corresponds to a 28 μm spot on the S-056 film Two hundred and fifty six levels of gray (8 bit accuracy) should also be an adequate quantization resolution since photo-multiplier shot noise will most likely dominate the least significant bit anyway.

SDC has proposed an image dissector scanner for use in general sampling operations for S-056. This scanner samples with an effective aperture of 17 μm and features a variable sampling dwell time so that improved signal to noise figures can be obtained by taking more time at each sample point. Figure 2-10 tabulates the scan speed, time required for scanning one frame, and the number of effective gray levels (number of noise-free significant bits). Effective gray levels are based on the percentage of codes that fall within plus or minus one code.

Scan Speed Option	#1	#2	#3	#4
Scan Time For 512 x 512 Array	5.7 min	88 sec	25 sec	9.2 sec
Sample Dwell Time (μs)	1280	320	80	20
S/N Ratio (DB)	41	35	29	23
Effective Gray Levels	238	164	82	41

Figure 2-10 Tabulation of Performance Data for Image Dissector Scanner

2.5.3   SCANNER NON LINEARITY

By scanning a number of neutral density filters, CSC was able to measure the
linearity of the Optronics scanner. Because this scanner utilizes a logarithmic
amplifier, the relationship between gray value and scanned film density is more
or less linear as can be seen from Figure 2-11 which is excerpted from the CSC
report. The image dissector scanner has a dual mode amplifier so that gray values
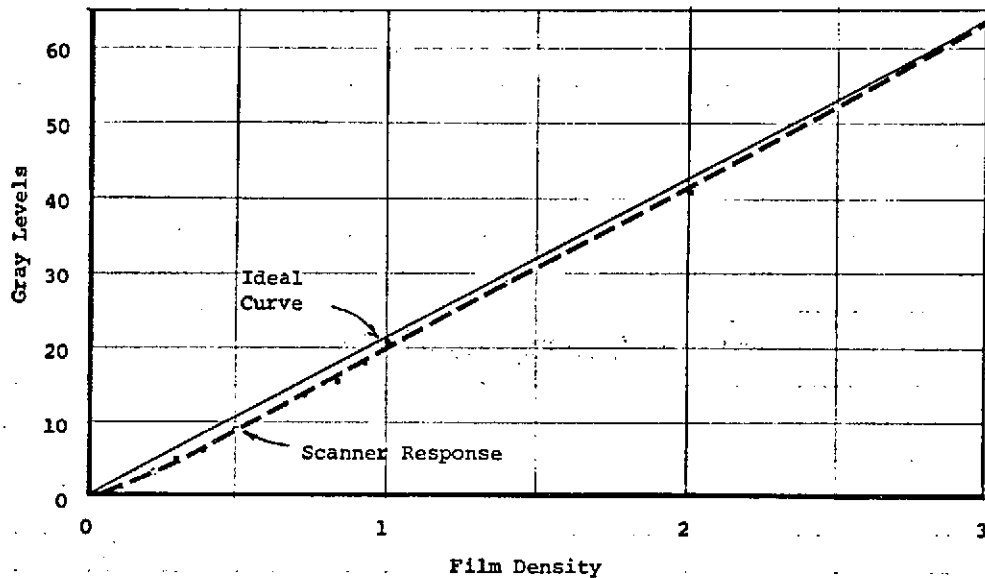may either be chosen to represent film densities or transmittance.

Figure 2-11   Plot of Measured Response of Optronics Scanner Against Ideal Curve

SECTION 3.   APPLICATION SEQUENCE STUDY

The purpose of the application sequence study was to determine the optimum order in which image processing techniques should be applied to achieve the best overall results.   This was to utilize real data frames from the S-056 program in investigating typical image processing sequences so as to provide a guideline for future processing.

First generation films were not available during this study and since some information was lost in the duplicating process of the second generation, it was not possible to proceed with the study using real data.   Therefore, a set of general guidelines was developed, in so far as possible, to assist in the image processing sequence determination effort.

In general, it is best to restore image degradations in the reverse of the order in which they occur.   That is -

- First correct for scanner non linearities.   This should be a simple reversal of the scanner characteristic curve as illustrated in Figure 2-11.   This will result in a conversion of the discrete scan data gray values to film density values.

- Convert film density values to radiation intensity values using the appropriate inverse of the film D $\log_{10}$E curve.   This conversion will automatically account for the inherent non linearities in the film response.

- Apply a two-dimensional correction algorithm (such as the IDAPS operator DEPENDENT ALTER) to compensate for the telescope vignetting which is dependent on position within the field of view.

- Compensate for the energy losses introduced by the telescope optics and spectral filters.   This may be accomplished as a part of the filter correction process.

- Finally, correct for optical distortions through the application of a deconvolution operator or a more general digital filtering operator.

The preceeding steps are intended to convert the gray values which are produced as output from the scanner into a set of values which have a linear relationship to spatial energy distributions. These steps are not always manditory and their order is somewhat flexible. Given accurate correction data, however, these steps should provide the researcher with restored data which is a good basis for further application of enhancement and/or analysis techniques.

SECTION 4. SUMMARY CONCLUSIONS

This report concludes NASA Contract NAS8-25471. During the four years of this contract, adequate knowledge has been gained to provide a firm basis for the development of an image processing hardware/software system capable of processing the film data that has been produced by the S-056 experiment during the Skylab mission. There are certain steps which should be taken in the immediate future to provide information about telescope performance and operating characteristics for use once the operational image processing system is built. These steps rely on the availability of accurate data from the Skylab missions themselves and from the post flight analysis of the data, the instrument, and the film. Continued study of S-056 system characteristics is still needed in four areas -

- Film Curves
- Field Efficiency and Geometric Distortion
- Filter Bandpass/Rolloff
- Telescope PSF

4.1 FILM CURVES

As mentioned in section 2.4, sensitometric study of the SO-212 film is not yet complete. Work is continuing, however, to refine and improve the accuracy of this data. Accurate sensitometry is of great importance to the qualitative analysis of the data and the development of accurate solar X-ray flux density profiles. Therefore, every effort should be made to provide accurate and complete sensitometry data as soon as possible and to keep this data up to date as new studies of the film are carried out.

Second generation films must not be allowed to saturate, but if the condition is unavoidable, then two copies should be made of each frame - one with low exposure to copy the low density regions of the original and the second with greater exposure to obtain recovery of the high density information. In any event, whether one copy or two are used, a means should be provided for keeping track of the first to second generation density to density conversion curve. One simple way to do this is to include a density wedge on the second generation film at the time the copy is made.

4.2 FIELD EFFICIENCY AND GEOMETRIC DISTORTION

The problems of determining telescope field efficiency and geometric distortion are grouped together because they share a common need for system performance information. Film from the S-056 program should be examined to locate a sequence of frames which was taken by the telescope during a short time period (about one hour) and which was taken with the telescope pointing at various off-axis angles. Information is needed from the ATM pointing control data records to determine the precise pointing reference of the telescope for each of the selected frames of imagery. By selecting a number of recognizable features in each frame and then comparing their relative intensities and locations against each other and against the pointing control data, a reasonably accurate description can be developed of the variations in instrument efficiency over the field of view and of the geometric distortions that take place as an object is viewed in different locations within the field of view.

4.3 FILTER BANDPASS/ROLLOFF

Figure 2-6(b) presented a gross picture of S-056 filter bandpass characteristics. Actually, the filters used by the telescope have a gradual rolloff which means that single frequency energy sources may be passed by several filters with varying levels of attenuation. Knowledge of the attenuation characteristic of each filter is a valuable tool in determining the frequency characteristics of features on an S-056 photograph.

Work is now being done to develop more precise filter characteristic curves based on the measurement of physical samples of the filter material. As soon as possible, the results of this work should be made available to the image processing project.

4.4 TELESCOPE PSF

The determination of the S-056 telescope PSF has received more attention by this project during the past four years than any other feature of the instrument. A considerable effort was devoted to determining the PSF from images of test bar charts, and reasonably good results were obtained. The ground test photographs from S-056 exhibited a large amount of scattering which the PSF had to take into

account.   Recent real data frames from the telescope in space, however, does
not exhibit nearly as much scattering and so the actual PSF for the telescope
must be different from what was previously predicted.   As mentioned before,
several frames from the program contain very compact, high energy emission regions
which are so small in size that they might be considered as point sources in the
data.   It may be possible to measure the system PSF from these point sources
directly.   To do this, those frames containing the compact emission regions must
be identified.   In order to reduce error, the original films should be used and
as many samples as possible taken for the measurement.

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